Attachment 1 to JPN-98-xxx

General Electric Nuclear Energy Report

GENE-187-30-0598 NP, B13-01920-30, Revision 0,

"CRD Bolting Flaw Evaluation for James A. FitzPatrick Nuclear Power Plant",

October 1998

(non-proprietary)

New York Power Authority

JAMES A. FITZPATRICK NUCLEAR POWER PLANT
Docket No. 50-333
DPR-59

GE Nuclear Energy

TECHNICAL SERVICES BUSINESS
GE Nuclear Energy
175 Curtner Avenue, San Jose, CA 95125

GENE-187-30-0598 NP
Revision 0
DRF # B13-01920-30
Class I
October 1998

CRD Bolting Flaw Evaluation for James A. FitzPatrick Nuclear Power Plant

October 1998

Prepared for

New York Power Authority

Prepared by

GE Nuclear Energy
San Jose, California

NEW YORK POWER AUTHORITY

DOCUMENT REVIEW STATUS

STATUS NO:

1 ☑ ACCEPTED

2 ☐ ACCEPTED AS NOTED RESUBMITTAL NOT REQUIRED

3 ☐ ACCEPTED AS NOTED RESUBMITTAL REQUIRED

4 ☐ NOT ACCEPTED

Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods or materials developed or selected by the supplier and does not relieve supplier from full compliance with contractual negotiations.

REVIEWED BY: R Perry TITLE: Director

RP DATE: 10/12/98

CRD Bolting Flaw Evaluation
for
James A. FitzPatrick Nuclear Power Plant

October 1998

Prepared by: Sylvia van Diemen
Sylvia van Diemen, Project Integrator
Structural Mechanics & Materials

Verified by:
H.S. Mehta, Principal Engineer
Structural Mechanics & Materials

Approved by: T A Caine
T.A. Caine, Manager
Structural Mechanics & Materials

IMPORTANT NOTICE REGARDING

CONTENTS OF THIS REPORT

Please Read Carefully

TABLE OF CONTENTS

List of Figures

List of Tables

1. INTRODUCTION & BACKGROUND

During routine control rod drive (CRD) maintenance at several BWRs, visual examination of cap screws that connect the CRD to the housing flange revealed circumferential cracking and corrosion pitting in the shank directly below the cap screw head. The cracks were first discovered at a BWR plant in May 1988 and reported in GE RICSIL No. 019 [1]. SIL No. 483, Rev. 2 [2] updated the information on the evaluation of CRD cap screw indications discovered at other GE BWRs and recommended corrective actions.

The original CRD cap screws at J.A. FitzPatrick Nuclear Plant (JAFNP) were 1-inch nominal diameter and were made of AISI 4140 which meets the requirements of SA193 Grade B7 of the ASME Code. Figure 1-1 shows the geometry of a CRD cap screw of original design. New York Power Authority (NYPA), the operator of the JAFNP, has been replacing the CRD cap screws in accordance with SIL 483, as the cap screws are removed during normal maintenance, since 1991. The replacement cap screws are of the new design as recommended in Reference 2.

The metallurgical evaluation of cracked cap screws from several BWR plants conducted by GE has shown that the observed cracking, mainly near the head to shank fillet, is very shallow and the crack tips have typically blunted appearance indicating insignificant crack growth expected during future operation. Also, the structural and fracture mechanics evaluations show significant margin.

The procedures in the ASME Code Section XI of record at JAFNP [3c] require a sample expansion if the indications in the removed cap screws exceed the acceptance standards of Table IWB-3517. The metallurgical and structural margin evaluations have shown that these requirements represent unnecessary hardship for the plant without significant added safety benefit.

The objective of this report is to develop the technical justification for not expanding the sample size when cap screws with cracks exceed the acceptance standards of Section XI. The justification is based upon review of metallurgical evaluations from several plants and a structural margin evaluation.

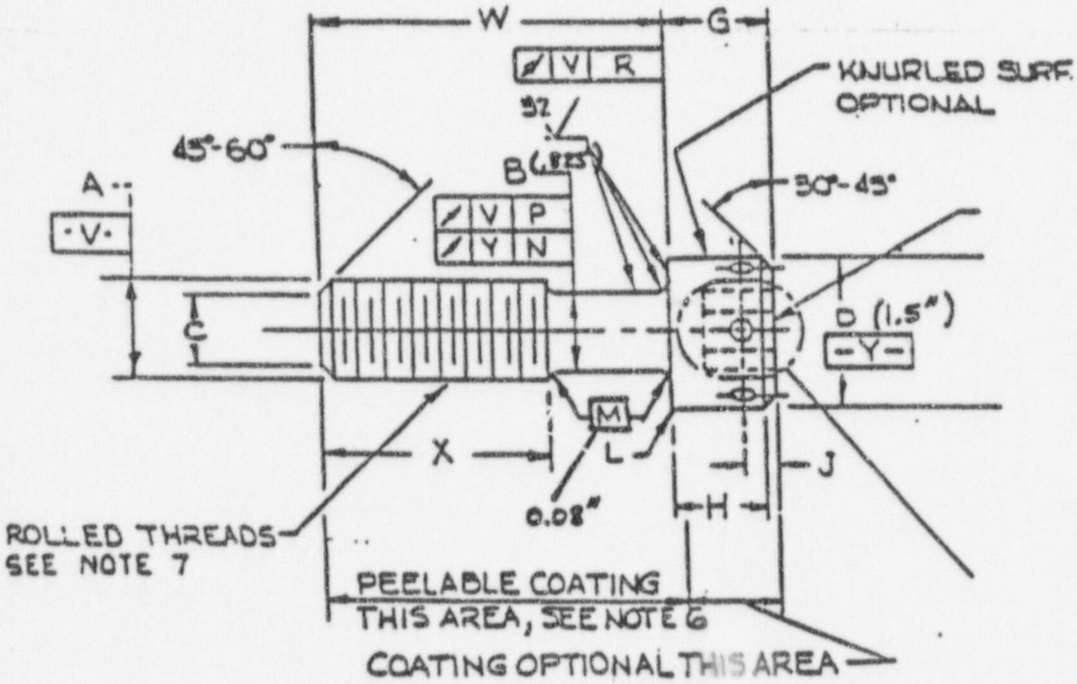

Figure 1-1 CRD Cap screw Geometry
(from GE Dwg. 117C4515P2, Rev. 6 [5])

2. REVIEW OF METALLURGICAL EVALUATIONS

To characterize the observed indications on CRD cap screws, metallurgical evaluations have been performed by several plants. The following paragraphs describe the results from eight (8) plants. These evaluations were performed by both GE and other laboratories.

2.1 Plant A

2.2 Plant B

2.3 Plant C

2.4 Plant D

2.5 Plant E

2.6 Plant F

2.7 Plant G

2.8 JAFNP

During visual examination of CRD cap screws, only six cap screws (out of 306 examined) were identified as having indications in excess of the ASME Section XI criteria. Two of the six cap screws were then sent out for metallurgical examination to characterize the flaws. These cap screws were selected based upon the longest linear indications and/or severest general corrosion.

The observed cracks were wide with blunted tips, similar to the cracking observed in all the other plants. The cracks were also filled with oxide, which indicated a corrosion mechanism was operating. The tempered martensite microstructure was consistent with the material for the bolts. The maximum observed crack depth was 0.036".

The conclusion of the evaluation was that stresses may have had some effect on the cracking, but that corrosion was the dominant mechanism. Again, this is a different interpretation of the mechanism; however, the depth and crack morphology are similar to the other investigations.

2.9 Conclusions From Review of Metallurgical Examinations

Figure 2-1: Indications on CRD cap screw from Plant B; crack is approximately 0.045" long.

Figure 2-2: Cracking on CRD cap screw from Plant B; appearance is similar to corrosion pits.

Figure 2-3: 250X view of crack from Figure 2-1; note blunted tip.

Figure 2-4: Crack from Figure 2-2; crack has appearance of corrosion pit.

Figure 2-5: Head-to shank transition region #1 (Plant C)

Figure 2-6: Head-to shank transition region #2 (Plant C)

Figure 2-7: Cracking from Figure 2-5

Figure 2-8: Cracking from Figure 2-6

Figure 2-9: Visual indications, Plant D

Figure 2-10: Visual indications on second cap screw from Plant D

Figure 2-11: Cracking from Figure 2-9

Figure 2-12: Cracking from Figure 2-10

3. ALLOWABLE FLAW DEPTH EVALUATION

The allowable crack depth is governed by two different criteria:

(i) Fracture mechanics assessment
(ii) Needed area to meet Section III limits

3.1 Fracture Mechanics Assessment

A key material property in the fracture mechanics evaluation is the K_{IC} value of the cap screw material. While the K_{IC} values for the cap screws were not directly measured, a good estimate of it can be made from the measured Charpy energies reported in the certified material test reports (CMTRs) of a large batch of the cap screws.

The following relationship called the Rolfe-Novak-Barsom correlation [4], was used:

$$(K_{IC}/S_y)^2 = 5\,[(CVN/S_y) - 0.05] \qquad (1)$$

where K_{IC} = Critical plane-strain stress intensity factor at slow loading rates, ksi√in.

S_y = 0.2% offset yield strength at the upper shelf temperature, ksi.

CVN = Standard Charpy V-notch impact test value at the upper shelf, ft-lbs.

The CRD cap screws in use at the FitzPatrick station were ordered per the Reference 5 specifications. Three Charpy tests were conducted on each batch consisting of up to 2000 cap screws. A total of 13 batches were involved. GE CMTR records were searched to obtain these values and are given in Table 3-1. In addition, GE searched its records of Charpy values from the tests conducted on cap screws received for metallurgical evaluation from one of the BWR plant. The last entry in Table 3-1 which pertains to CVN value from FitzPatrick station, was obtained from Reference 8. All of the Charpy values are based on tests conducted at 40°F, except the FitzPatrick CVN test which was conducted at 10°F, and were determined to be 100% shear fractures indicating upper shelf conditions.

Results of the statistical evaluation of the Charpy data in Table 3-1 are shown at the bottom of that table. The mean Charpy value was calculated as 88.6 ft-lbs and the standard deviation was calculated as 9.2 ft-lbs. This would indicate a mean minus two sigma value of (88.6-2x9.2) or 70.2 ft-lbs. A mean minus two sigma value approximately represents a confidence level in excess of 97% that the Charpy value of any cap screw will not be below 70.1 ft-lbs. The lowest value noted in Table 3-1 is 68 ft-lbs.

The cap screw material meets the requirements of ASME Code bolting material SA193, B7 for which the specified minimum yield strength is 105 ksi. Based on this value of yield strength and the assumed minimum value of 68 ft-lbs for the Charpy energy, Equation (1) predicts a K_{IC} value of 181.5 ksi√in.

The fracture mechanics based IWB-3600 evaluations in ASME Section XI [3] typically assume safety factor values of √10 or 3.16 for normal (Level A), upset (Level B) and test conditions and √2 or 1.44 for emergency (Level C) and faulted (Level D) conditions. Thus, the allowable value of K_{IC} for normal/upset/test conditions is (181.5/3.16) or 57.4 ksi√in.

The applied values of stress intensity factor, K_{app} were calculated using the 360° circumferential flaw solution from Tada and Paris flaw handbook [6]. The K_{app} is given by:

$$K_{app} = \sigma \{\sqrt{(\pi c)}\} \{1.122 - 1.302(c/b) + 0.988(c/b)^2 - 0.308(c/b)^3\}/\{(1-c/b)^{3/2}\} \quad (2)$$

where,
- σ = Applied stress based on nominal un-cracked cross-section
- c= Circumferential crack depth
- b= radius of cap screw

The applied stress σ was calculated as 54.9 ksi [7]. This value includes the stress due to preload, thermal differential expansion and the shear stress resulting from friction. A tightening torque of 375 ft-lbs. was assumed in calculating the applied stress. A trial-and-error solution gave an allowable circumferential crack depth of 0.15 inch (i.e., the K_{app} is equal to the allowable value of 57.4 ksi√in at c = 0.15 inch).

Based on the preceding the allowable value of crack depth for the cap screws is 0.15 inch from fracture mechanics considerations.

3.2 Required Area to Meet Section III ASME Code Criteria

Reference 7 describes the analysis of the CRD bolted joint using typical ASME Code, Section III, Subsection NB, procedures. The minimum cap screw cross-section area to meet the Code requirements was calculated as 1.61 in^2. This is equivalent to the sum of cross-sectional areas of three cap screws. In other words, only three uncracked cap screws out of eight cap screws present at a CRD flange, are sufficient to meet the Code structural margins.

Assuming that all cap screws at a CRD flange experience cracking, the minimum cross-section area needed for each cap screw is (1.61/8) or 0.2025 in^2 or approximately a core area of 0.25 inch radius. The radius of the cap screws in the shank region where cracking has been observed is 0.41 inch. Therefore, uniform fully circumferential cracks of (0.41-0.25) or 0.16 inch depth in all eight cap screws at a CRD flange are acceptable while still maintaining the ASME Code required structural margins.

3.3 Allowable Flaw Depth Based on Section XI Acceptance Standards

Table IWB-3515-1 of ASME Section XI provides the acceptance standards for indications that may be detected during the volumetric examinations of cap screws greater than 2-inch nominal size. When a fully circumferential indication (aspect ratio approx. Equal to zero) is postulated, the allowable depth in Table IWB-3515-1 is 0.075 inch. The Code does not provide any guidance for cap screws less than 2-inch diameter. For the CRD cap screw which is 1-inch diameter (nominal size), a linear-elastic fracture mechanics (LEFM) analysis was conducted in Reference 8 and an equivalent allowable depth of 0.071 inch was extrapolated based on the values given in Table IWB-3515-1 for bolting greater than 2-inch in size.

3.4 Allowable Flaw Depth Summary

The preceding fracture mechanics and Code required area calculations indicate that CRD flange integrity is assured with required ASME Code margins even with 360° circumferential cracks of up to 0.15 inch depth in all cap screws. The acceptance standards which require no analysis, allow a crack depth of 0.071 inch. Thus, the maximum allowable flaw depth is 0.15 inch.

3.5 Comparison with Observed Crack Depths

A comparison of the allowable flaw depth of 0.15 inch with the observed crack depths in CRD cap screws is presented next.

GE Nuclear Energy has conducted several metallurgical analyses of the cracked cap screws as described in Section 2. The measured crack depths obtained in such analyses were reviewed and are summarized in Table 3-2. The crack depths for the FitzPatrick plant CRD cap screws were obtained from Reference 8. As noted at the bottom of Table 3-2, the mean value of the measured crack depths was 0.025 inch with a standard deviation of 0.015 inch. The deepest crack depth reported was 0.065 inch. The largest crack depth for FitzPatrick plant cap screws reported in Reference 8 is 0.036 inch. If one were to calculate the mean plus three standard deviation (99% probability) value, it would be (0.025 + 0.015x3) or 0.070 inch.

The deepest observed crack depth measured in cracked CRD cap screws removed from service at JAFNPP is 0.036 inch.

Based on the preceding comparison, it can be concluded that the observed crack depths in CRD cap screws removed from service are much less than the allowable crack depth that still maintains the structural margins consistent with the ASME Section XI requirements. The significance of this conclusion in terms of the ASME Section XI inspection program for the CRD cap screws is discussed in the next section.

Table 3-1 Measured Charpy Energies of CRD Cap screws

Table 3-2 Measured Crack Depths in CRD Cap screws

4. ASME SECTION XI EXAMINATION CONSIDERATIONS

There are two ways in which the examination of CRD cap screws can be triggered. One is when the CRD housing is disassembled for some reason such as refurbishment. Examination category B-G-2, Item No. B7.80 in Table IWB-2500-1 specifies a visual VT-1 examination of cap screws, studs, and nuts when the CRD housing is disassembled. The acceptance standard is specified in IWB-3517. The other way is if a CRD exhibits leakage during the system pressure test (IWA-5250). The need for sample expansion in the first case is the subject of discussion in this section.

4.1 IWB-2500-1 Examinations

If the indications exceed the acceptance standards, additional examinations are required. Paragraph IWB-2430(a) states, "Examinations performed in accordance with Table IWB-2500-1 that reveal indications exceeding the acceptance standards of Table IWB-3410-1 shall be extended to include additional examinations at this outage. ....."

The interpretation from the preceding paragraph is that additional examinations in Category B-G-2 may be required following the evaluation results of examinations performed in accordance with Table IWB-2500-1.

It is surmised that the intent of the Code in requiring the sample expansion was to assure that the extent and the nature of cracking exceeding the acceptance standards observed in a category during the current examination scope is not found elsewhere or more severe in the remaining components of the same category. Metallurgical examination results of cracked CRD cap screws from nine plants reviewed in Section 2 showed that this type of cracking is shallow and well understood. Furthermore, the fracture mechanics and Code area requirements calculations presented in Section 3 showed that there is a significant structural margin with respect to any likely depth of cracking that may be present. These results provide a strong technical justification for eliminating the need for sample expansion.

In this connection, a recent Code Case N-547 [9] is relevant and is discussed next.

4.2 Code Case N-547

This Code Case pertains to alternative examination requirements for pressure retaining bolting of CRD housings:

Inquiry: What alternative to the requirements of Table IWB-2500-1, Category B-G-2 may be used for VT-1 visual examination of CRD housing bolts, studs, and nuts?

Reply: It is the opinion of the Committee that the VT-1 visual examination of CRD housing bolts, studs, and nuts is not required.

This Code Case, which is applicable from 1980 Edition with the Winter 1980 Addenda to and including 1995 Edition, eliminates the need for the VT-1 examinations of the CRD cap screws. By logical extension, it also eliminates the need for sample expansion triggered by the requirements of Paragraph IWB-2430(a). This Code Case was incorporated into the Code in the 1995 Addenda.

4.3 Inspection, Evaluation/Replacement Practice During CRD Housing Refurbishment

The current inspection, evaluation/replacement practice during the CRD housing refurbishment at JAFNP consists of replacing the cap screws with new design cap screws as suggested in Reference 2. If a previously installed cap screw is reused, VT-1 and augmented surface examinations prior to installation are performed per the GE SIL [2]. Given the metallurgical evaluations reported in Section 2, and structural margins shown and typical indication depths observed as discussed in Section 3, this practice is technically sound and meets the intent of the Section XI requirements for verification of acceptability for replacements (IWA-7220 for 1980 Edition or IWA-4150 for 1989 Edition of Section XI).

5. SUMMARY & CONCLUSIONS

This report summarizes the results of previous metallurgical analyses of cracked CRD cap screws conducted by GE and presents the results of structural margin evaluation. The results can be summarized as follows:

(a) The review of previous metallurgical evaluations of cracked CRD cap screws shows that the observed cracking is typically shallow (less than 0.065 inch) and the expected crack growth in future is insignificant.

(b) The allowable flaw depth is 0.15 inch considering both the Code cross-section area requirements and the LEFM considerations. This value considerably exceeds the deepest observed crack depth of 0.065 inch.

(c) The current inspection, evaluation/replacement practice during the CRD housing refurbishment at JAFNP consists of replacing the cap screws with new design cap screws as suggested in Reference 2. If a previously installed cap screw is reused, VT-1 and augmented surface examinations prior to installation are performed per the GE SIL [2]. This evaluation/replacement practice, coupled with results in (a) and (b), and the recently enacted Code Case N-547, which eliminates the requirement for VT-1 visual examination of the CRD cap screws, provide sufficient technical justification for not expanding the sample size when cracked cap screws are found during the refurbishment of the CRD housings.

6. REFERENCES

[1] GE RICSIL No. 19,"CRD Cap Screw Crack Indications," May 19, 1988.

[2] GE SIL No. 483, Revision 2,"CRD Cap Screw Crack Indications," August 5, 1992.

[3] ASME Pressure & Vessel Code.
(a) Section III, Rules for Construction of Nuclear Power Plant Components, Div. 1.
(b) Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 1980 Edition with Winter 1981 Addenda (2nd interval).
(c) Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 1989 Edition (3rd interval).

[4] J.M. Barsom and S.T. Rolfe, "Fracture and Fatigue Control in Structures - Applications of Fracture Mechanics," Second Edition, 1987, Prentice Hall, Englewood, NJ.

[5] GE Drawing No. 117C4515P2, Rev. 6; Applied Practice 209A4270, Rev. 1.

[6] Tada, H., Paris, P. and Irwin, G., "The Stress Analysis of Cracks Handbook," Second Edition, Paris Productions and Del Research Corporation, St. Louis, Missouri, 1985.

[7] GE Document 22A2016, Rev. 2, dated January 15, 1970.

[8] "Evaluation of CRD Cap Screw Defects James A. FitzPatrick Nuclear Plant," Report in NYPA File 62-B-0160, June 1997.

[9] ASME Section XI, Division Code Case N-547, "Alternative Examination Requirements for Pressure Retaining Bolting of Control Rod Drive (CRD) Housings," Approved August 24, 1995.

[10] GE Internal Communication from E.Y. Gibo to A.L. Jenkins; Subject: Browns Ferry 2 CRD Flange Leakage, April 13, 1991.